

The Dark Energy Survey and The Fate of the Universe

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The Era of Observational Cosmology

Two (competing!) observations of supernovae showed that the cosmos is dominated by a mysterious “Dark Energy” that drives the accelerated expansion of the universe, and subsequent observations utilizing different probes (e.g. CMB) have confirmed this result.

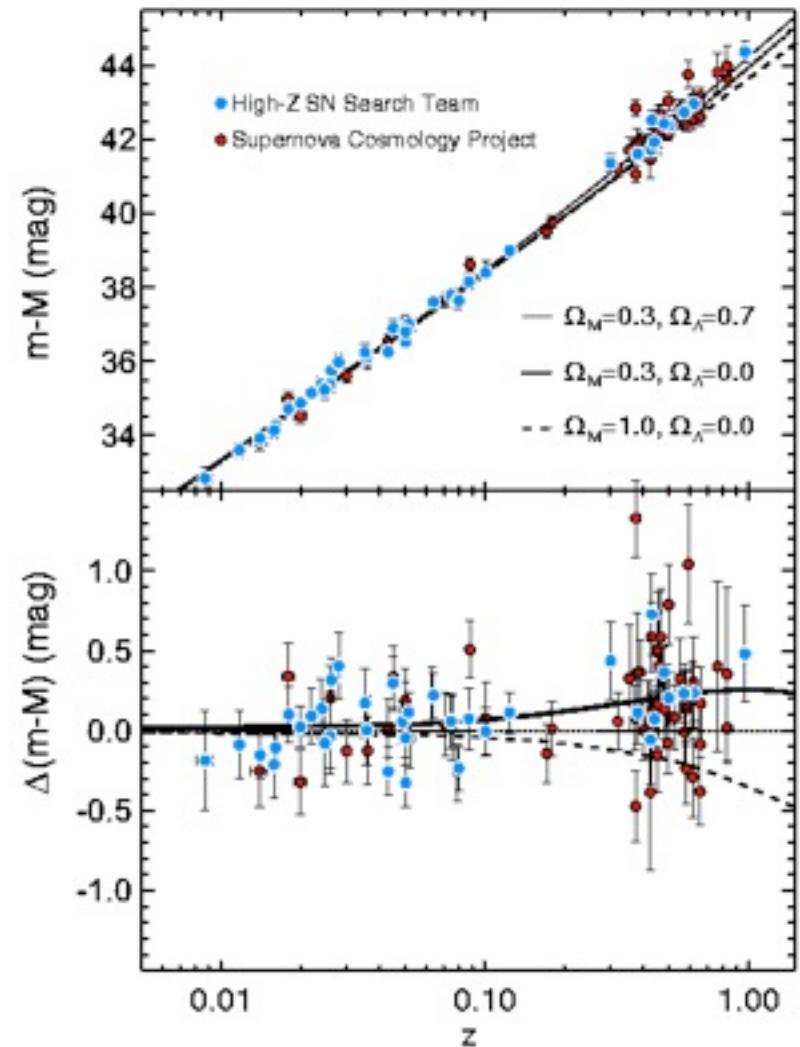
The properties of Dark Energy can be expressed in terms of its Equation of State at different redshifts:

$$w(z) = p/\rho$$

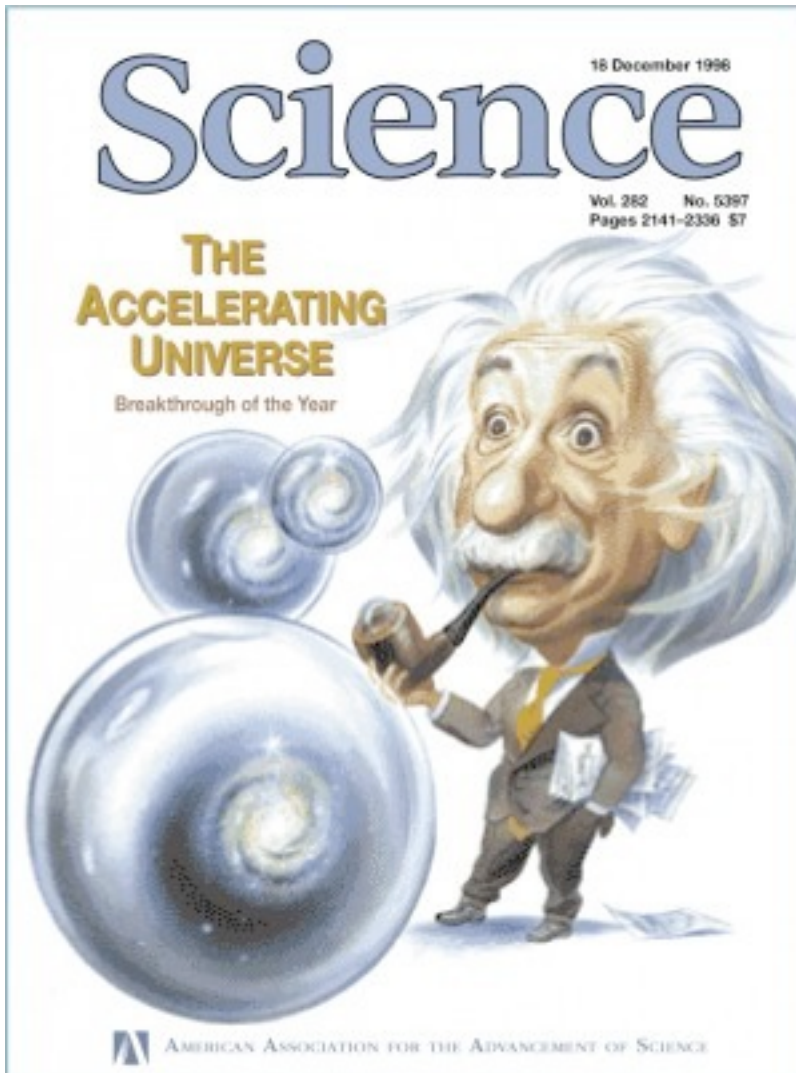
We parameterize $w(z)$ as follows:

$$w(z) = w_0 + w_a(1-a), \text{ where } a = (1+z)^{-1}$$

$w_0 = w_\Lambda$ (i.e. the cosmological constant) if $w_a = 0$.



The Discovery of Dark Energy is Big News...



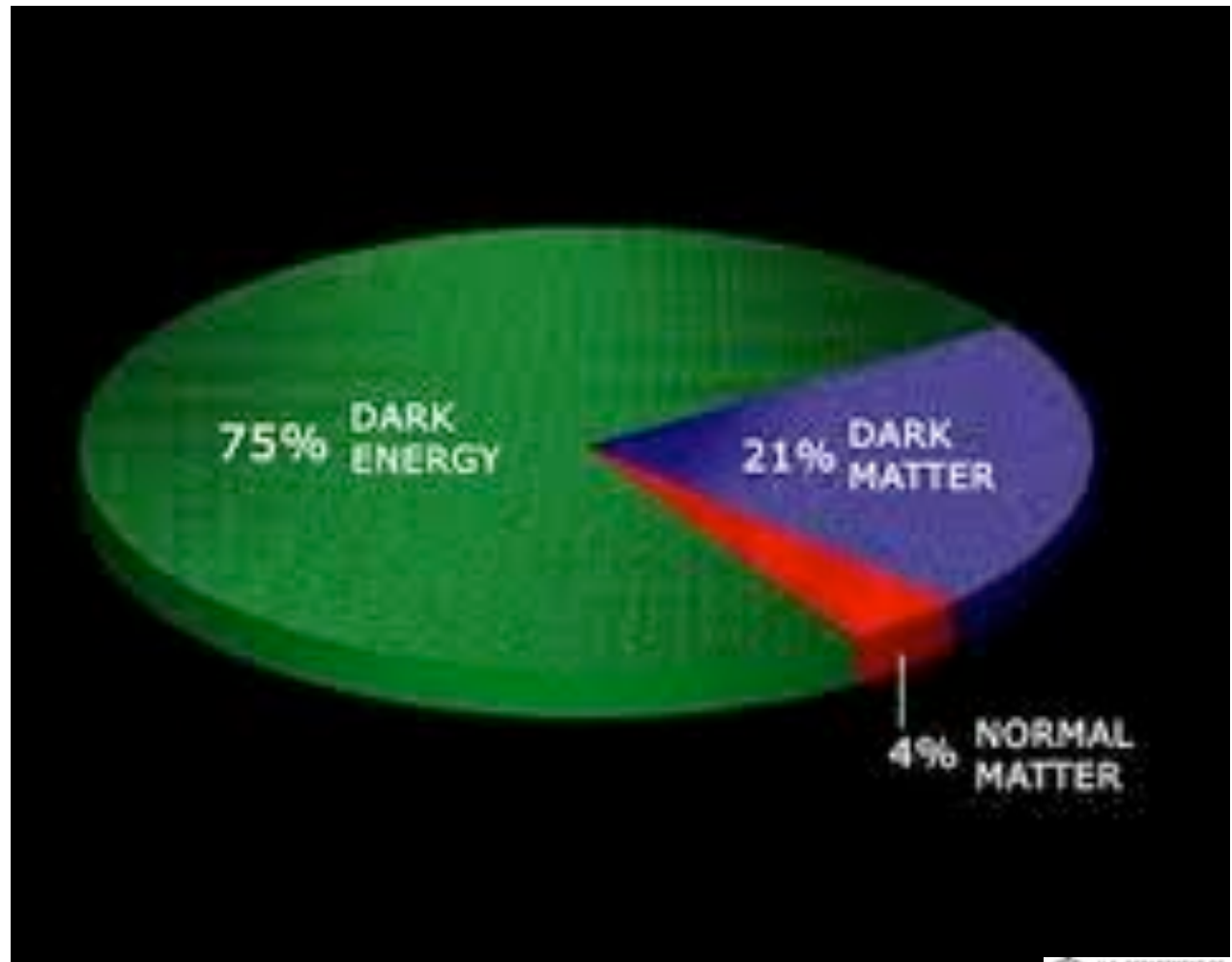
Science Magazine,
December 18, 1998



Nobel Prize in Physics, 2011

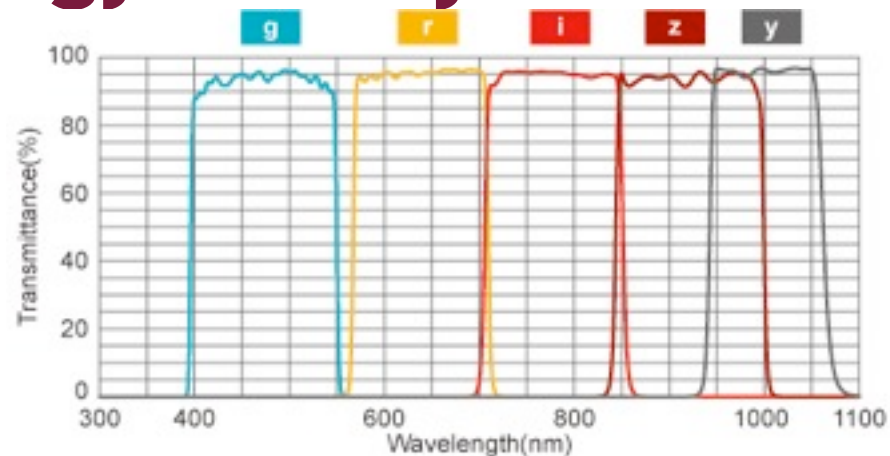
So, what is it...?

- Cosmological Constant?
- 10^{120} problem
- Dynamical Dark Energy?
- Modification of Gravity?
- Voids?
- Disfavored by HST Observations
- We don't know, yet...



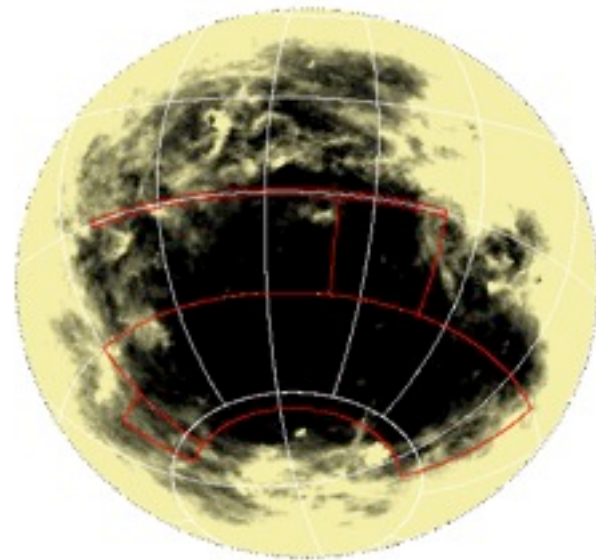
The Dark Energy Survey

Starting in 2012, DES will observe 5000 deg² of the southern sky over 525 nights with (SDSS-like) grizY filters. The DES “footprint” overlaps with VISTA Hemisphere Survey (DES Y-band data VHS JHK data), as well as SDSS, SPT, and Skymapper.



DES uses four complementary methods to constrain the Dark Energy Equation of State:

- Supernovae
- Galaxy Clusters
- Weak Lensing
- Large Scale Structure



The DES Instrument: DECam

The newly-constructed Dark Energy Camera will be installed at the prime focus of the 4m. Blanco Telescope at Cerro Tololo Inter-American Observatory in Chile. DECam consist of 62 2k x 4k extremely red-sensitive ($QE > 50\%$ at 1000nm) CCDs, plus associated guide/focus CCDs, with a field of view of approximately 3 square degrees.



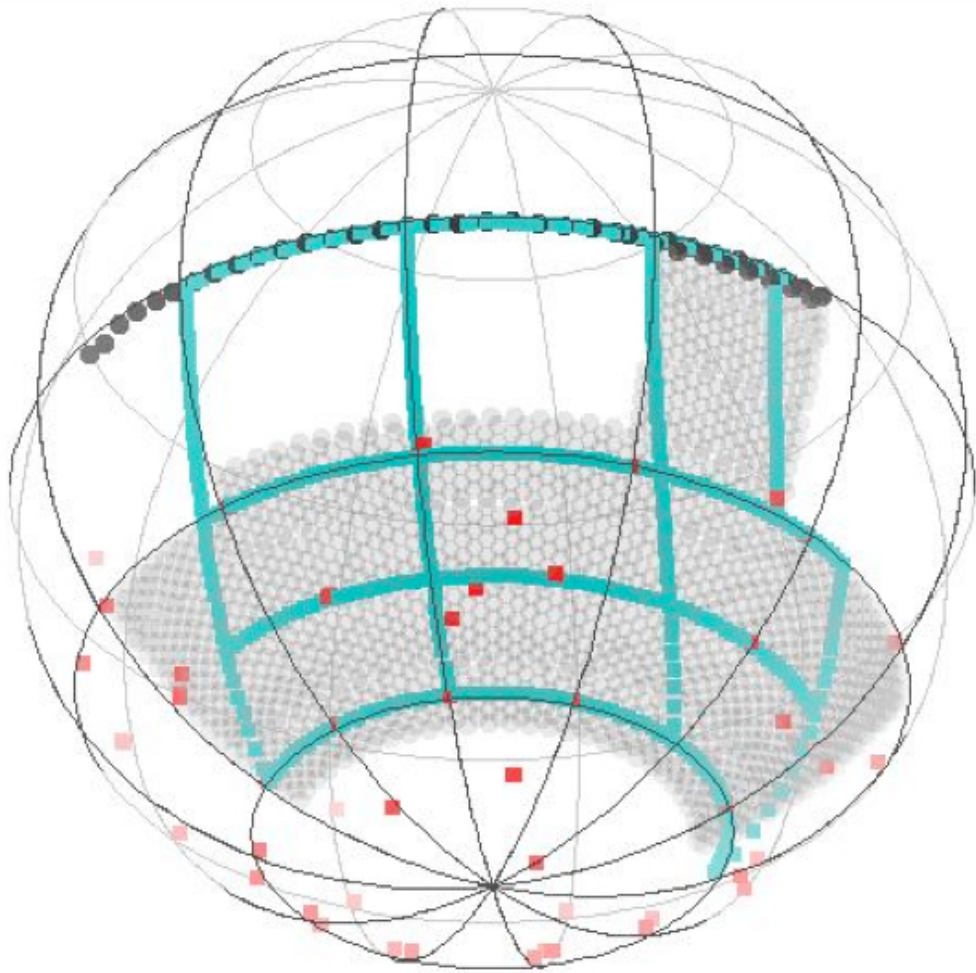
Argonne Contributions to the Dark Energy Camera

- Instrument Control System
- f/8 Handling System
- Telemetry/Alarms
- PreCam



Calibrating the DES: PreCam Grid & DES Footprint

Rib & Keel Strategy:
Every ~20 min during
the DES, a field
containing hundreds
of calibrated stars
will be observed.
These will be tied to
SDSS, USNO, and
Southern u'g'r'i'z'
Standard Stars.



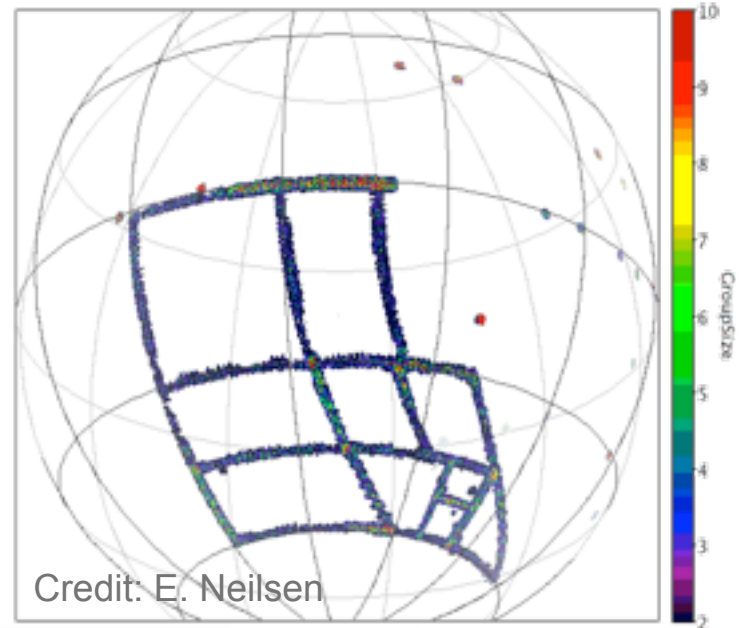
PreCam Goals and Timeline

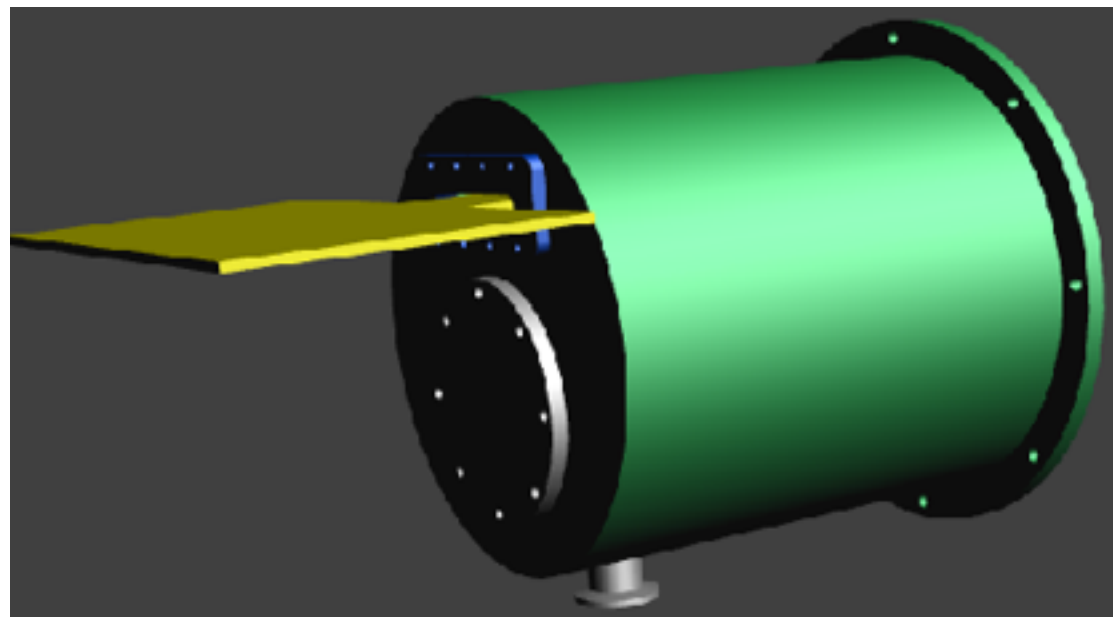
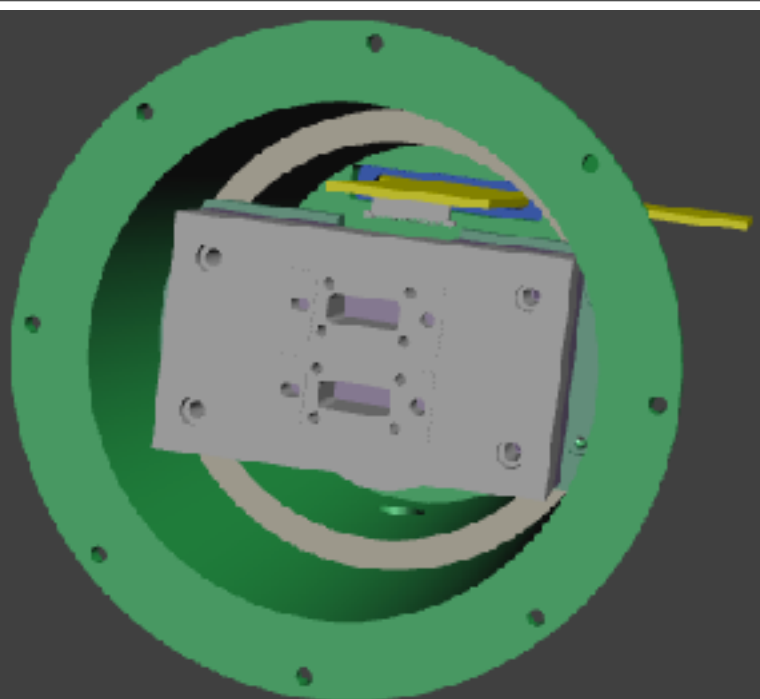
PreCam is a scaled down (2 CCD) version of the DECam that was used (in part) for development and testing of DECam hardware and software.

PreCam's primary goal was to observe a sparse grid of southern hemisphere standard stars ahead of the DES (especially in Y).

It was designed and constructed in less than one year. First orders for parts were placed in January 2010 and it achieved first light that August.

Precursor observations will allow DES to begin with photometric standards and save up to 10% of the DES observing time that would otherwise be devoted to calibration efforts.





PreCam Vessel

Focal Plane Support Plate

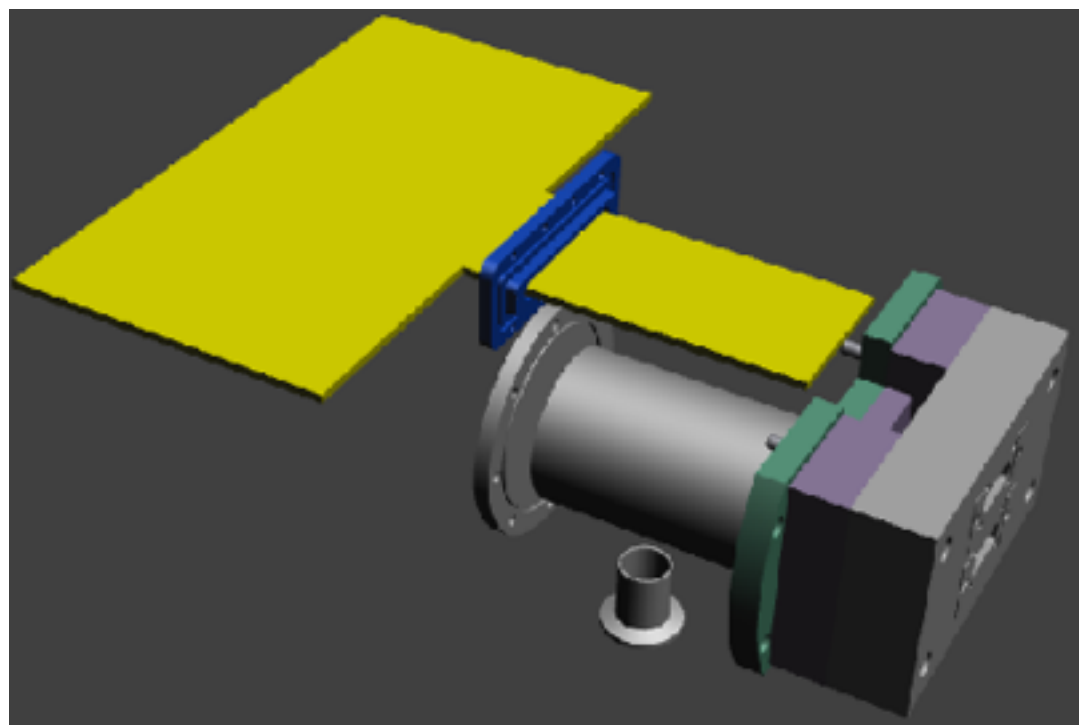
Thermal Transfer (Cu) Block

G-10 Mounting Block

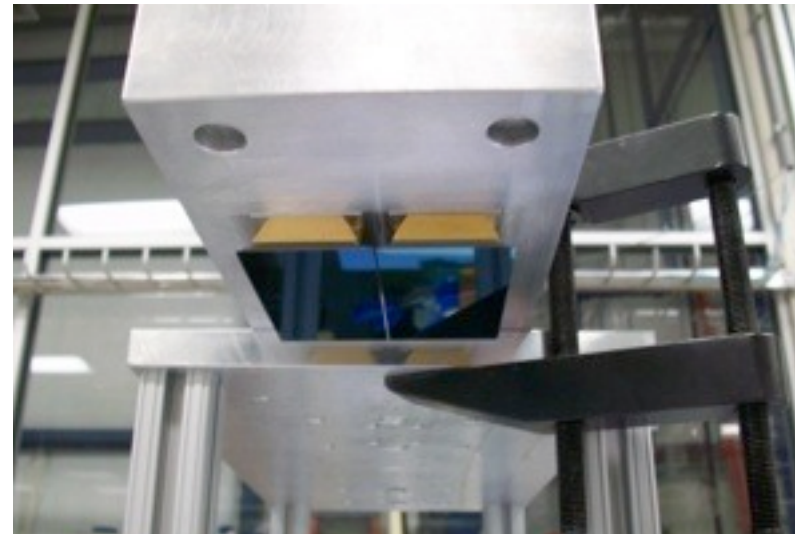
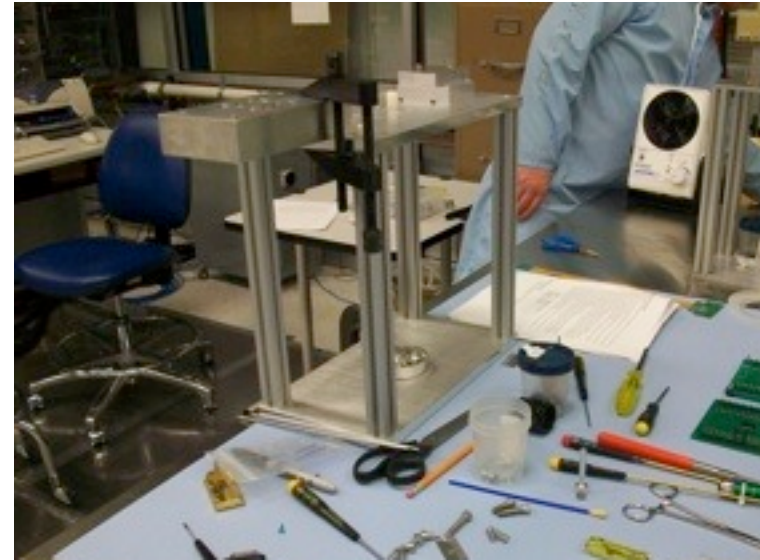
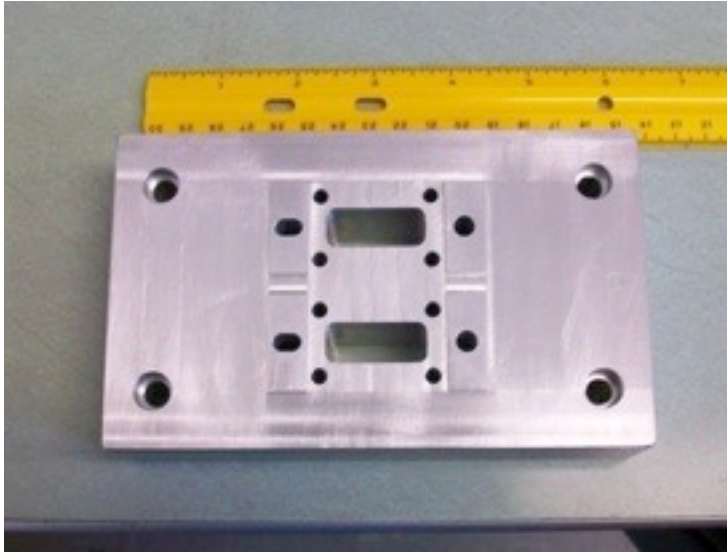
CryoTiger

Vacuum Interface Board

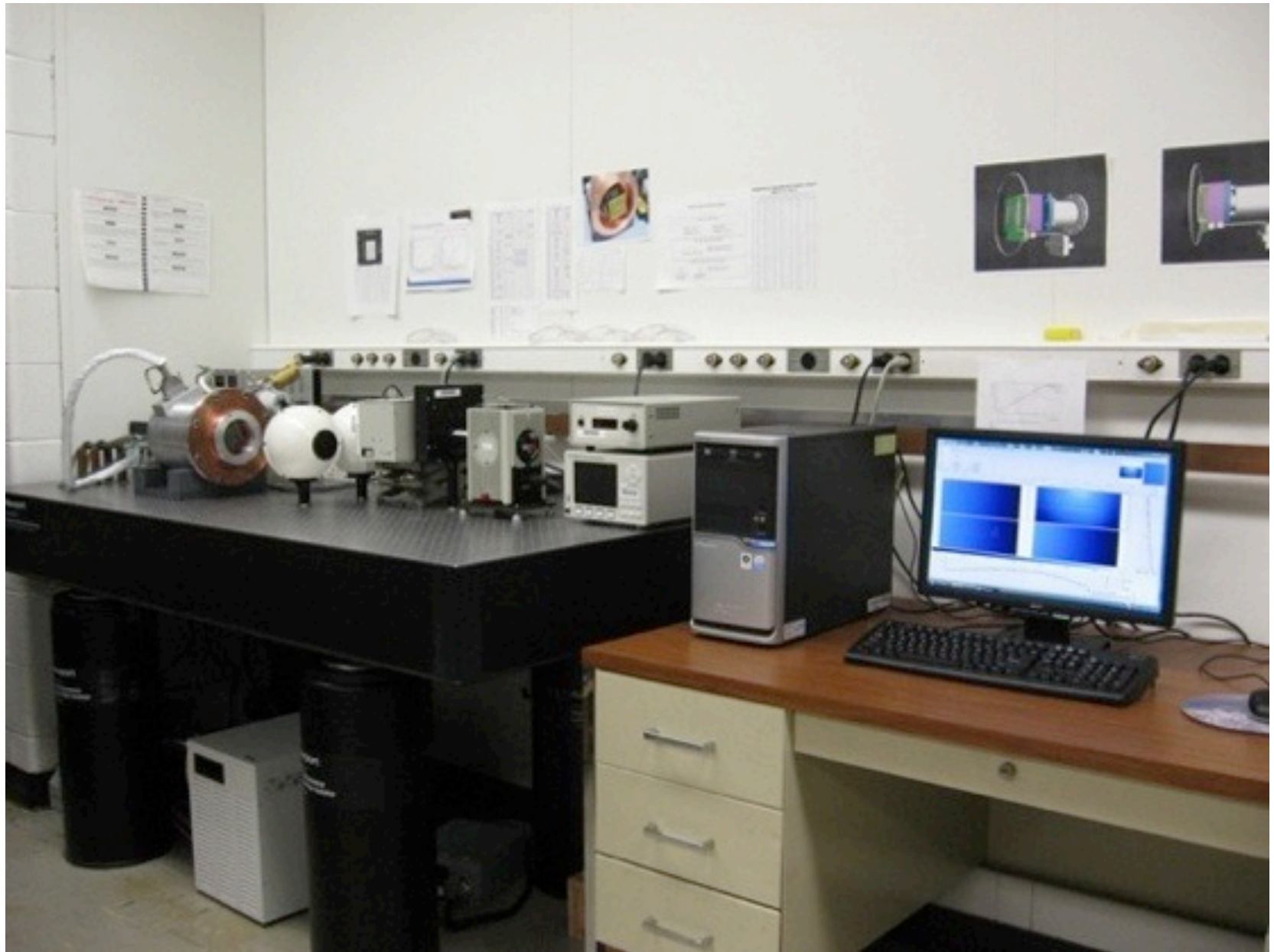
Dewar



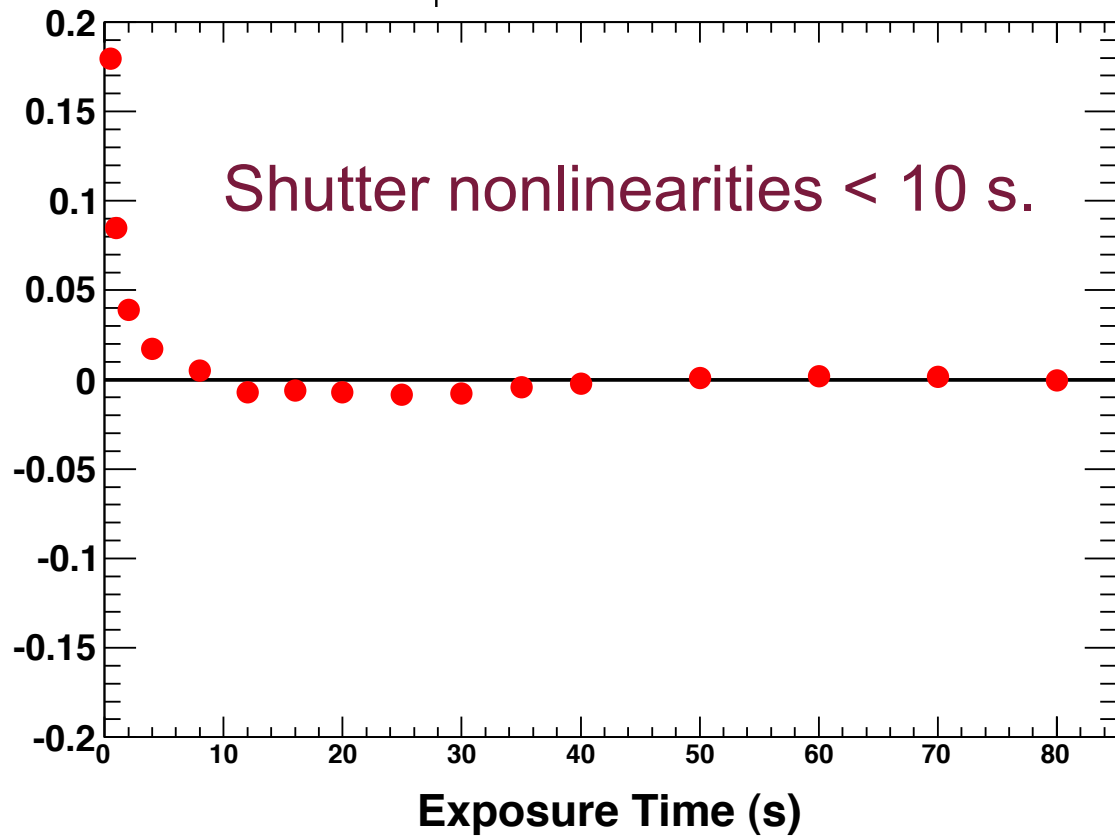
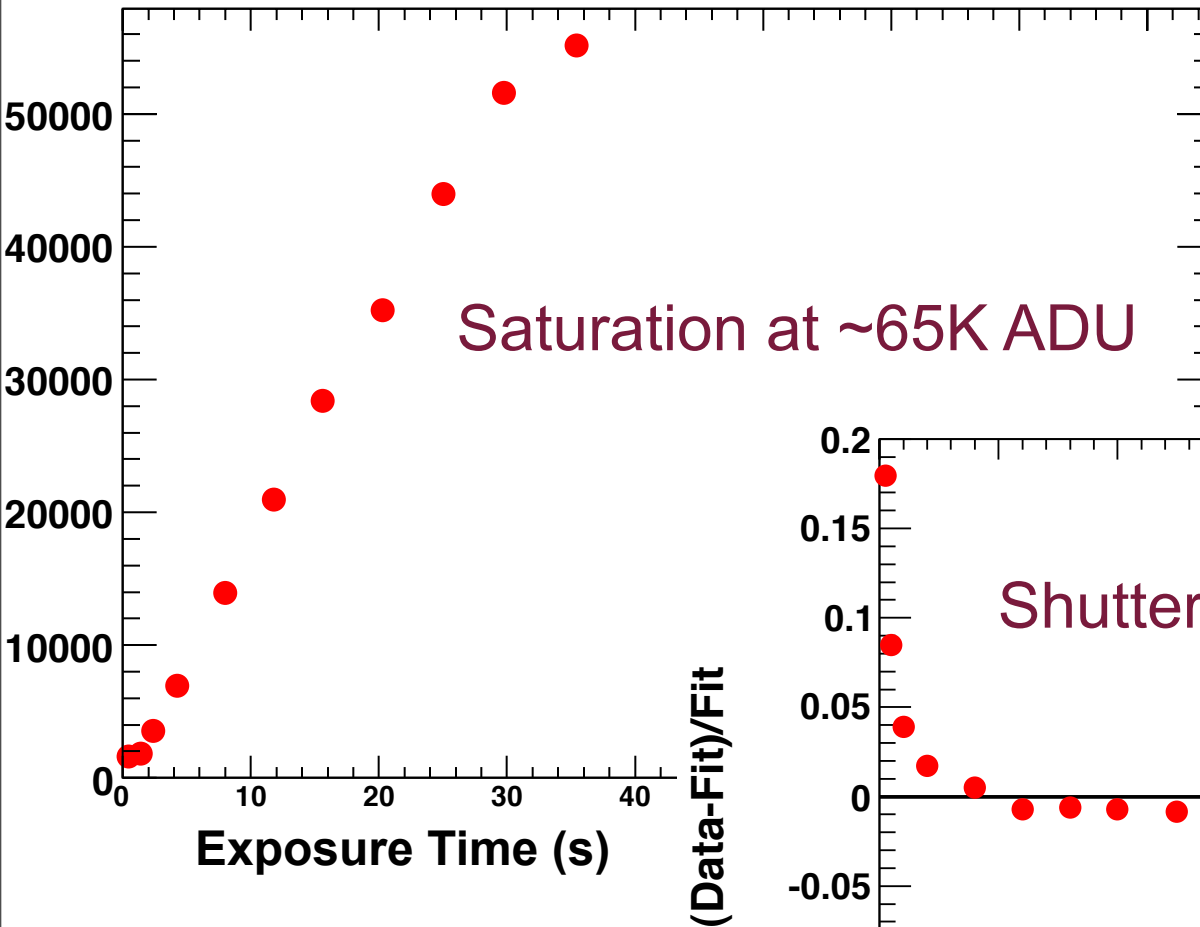
Focal Plane Support Plate & CCD Installation



Bench Tests I: Laboratory Setup



Bench Tests II: Linearity, Full Well



Installation on the Curtis-Schmidt Telescope at CTIO

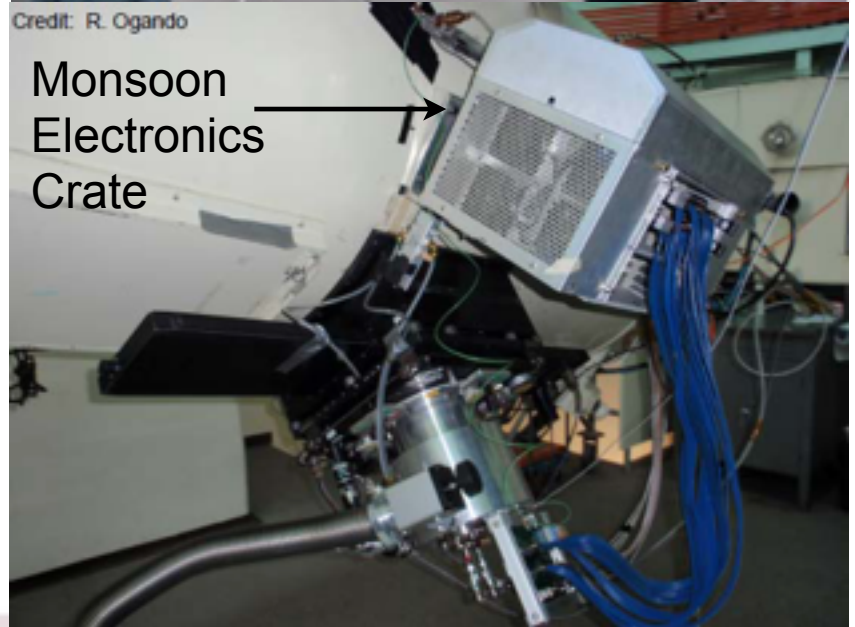


Credit: UofM Astronomy

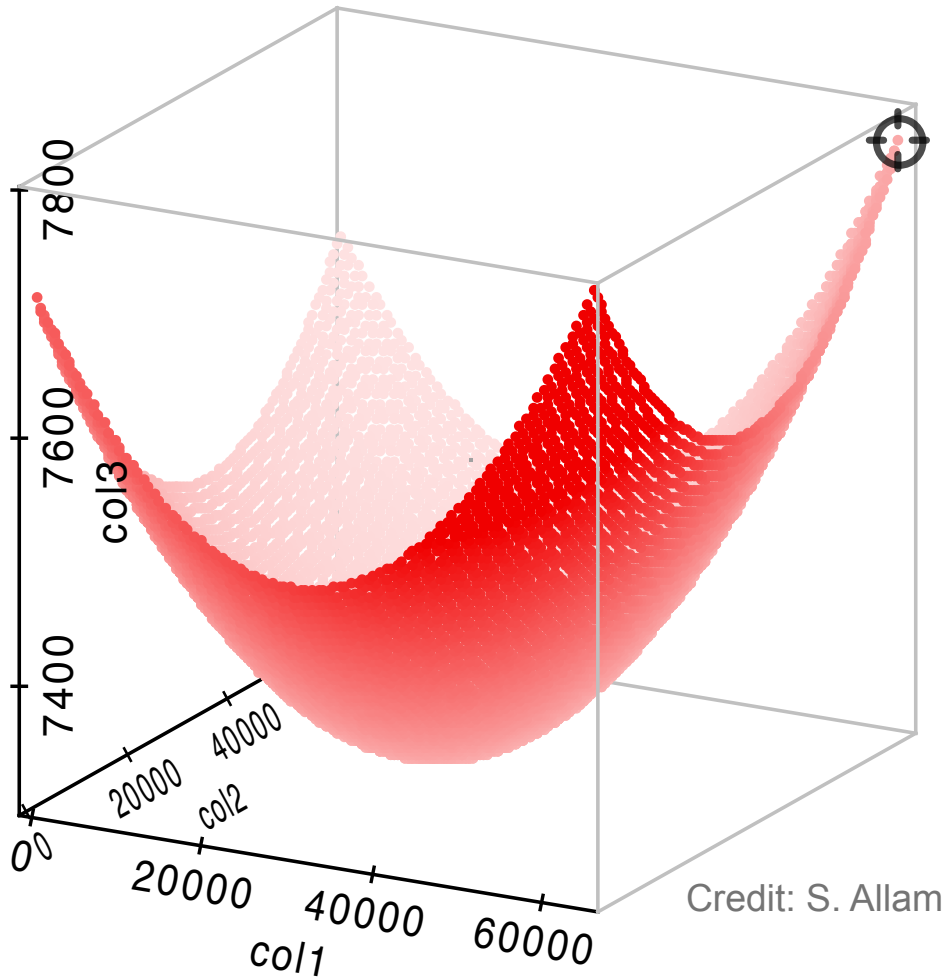


Credit: R. Ogando

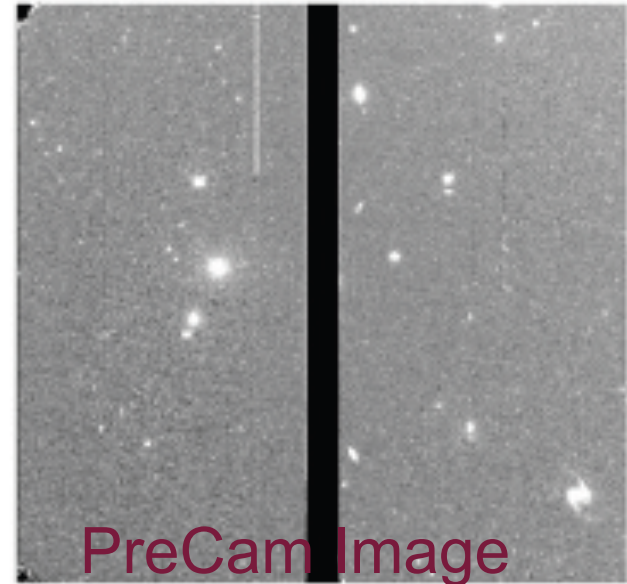
Monsoon
Electronics
Crate



Commissioning I: Best Focus Surface, Early Images



Note curved focus surface
due to lack of field flattener

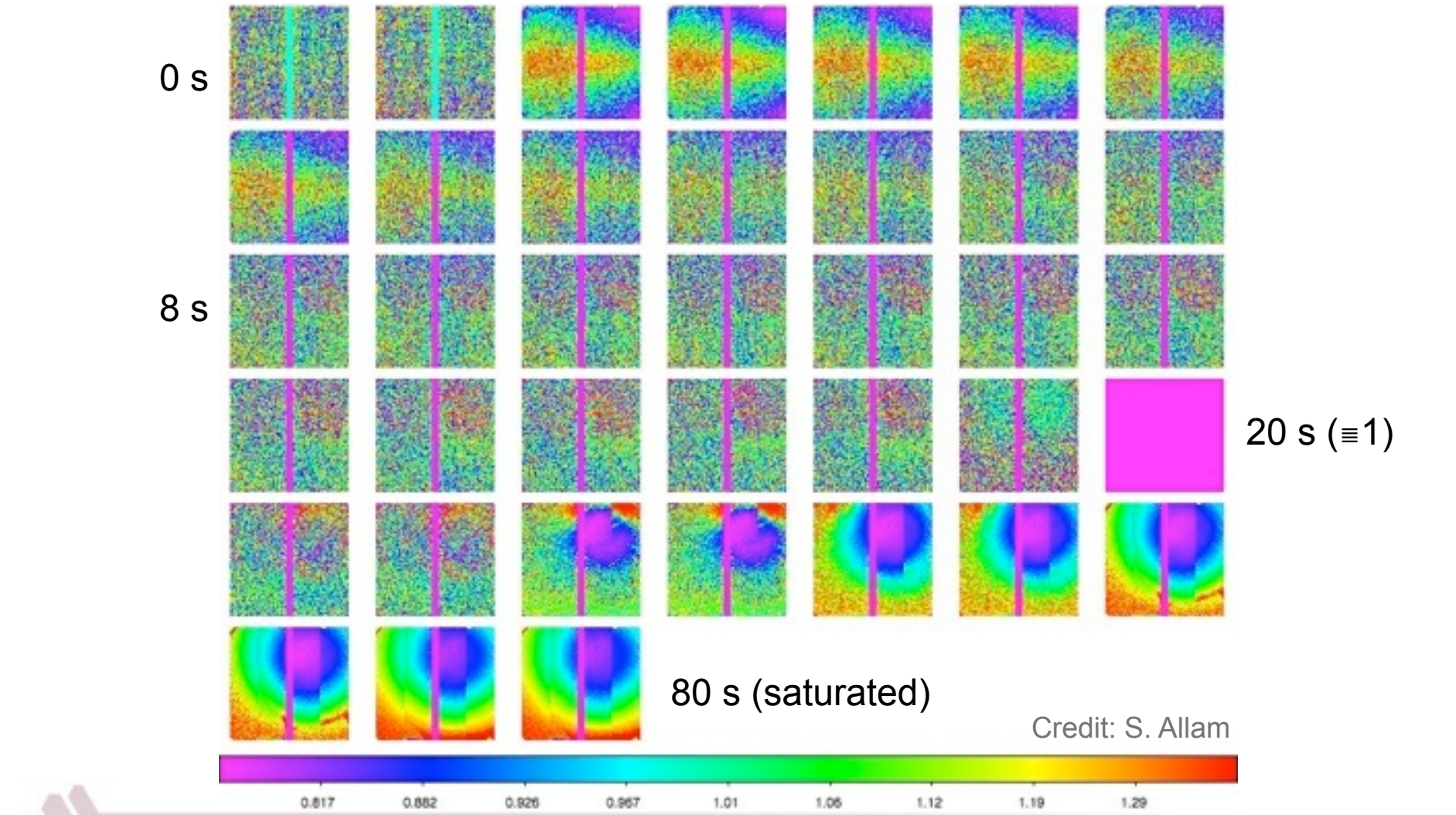


Prior Sky Survey Image



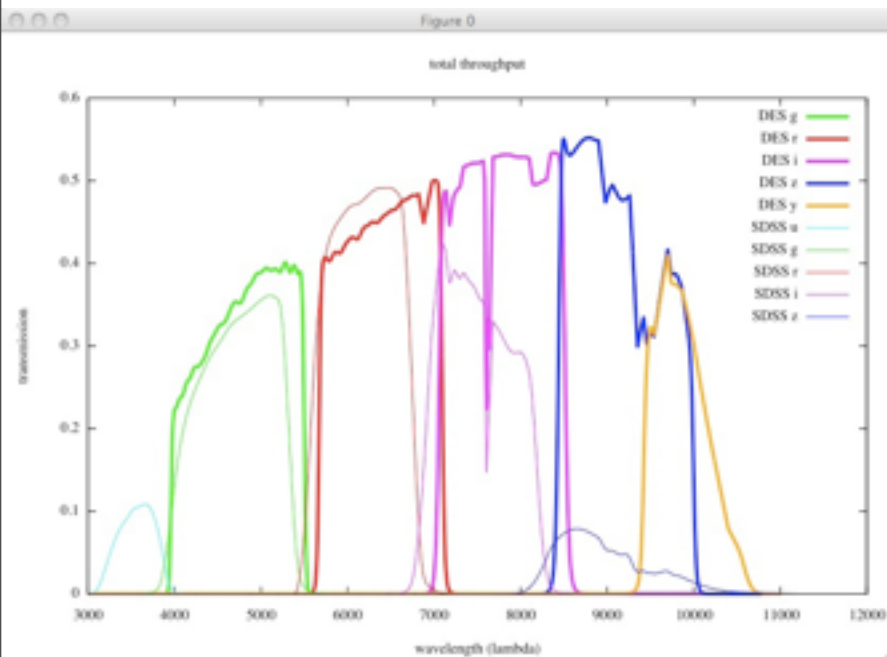
Commissioning II: Shutter Timing from On-Sky Data

nonzero shutter actuation time effects are negligible beyond ~8s,
confirming results of bench tests

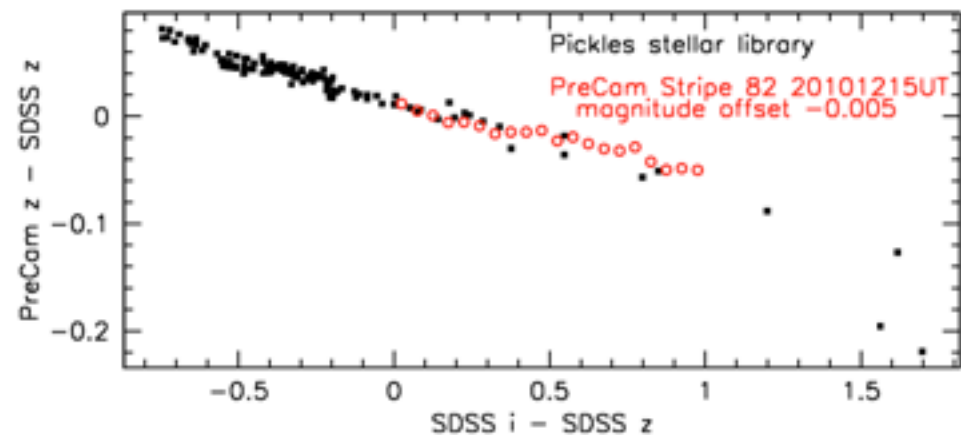
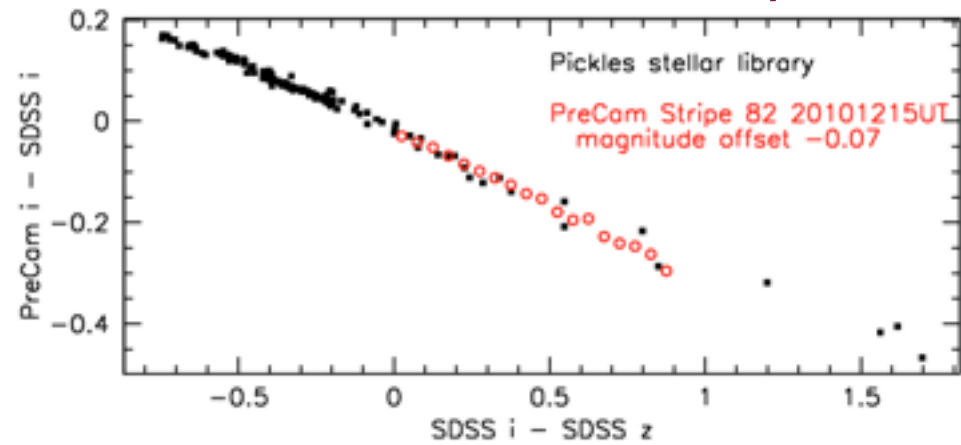


Commissioning III: Filter Performance

Transmission vs. Wavelength: DES Filters vs. Sloan Filters



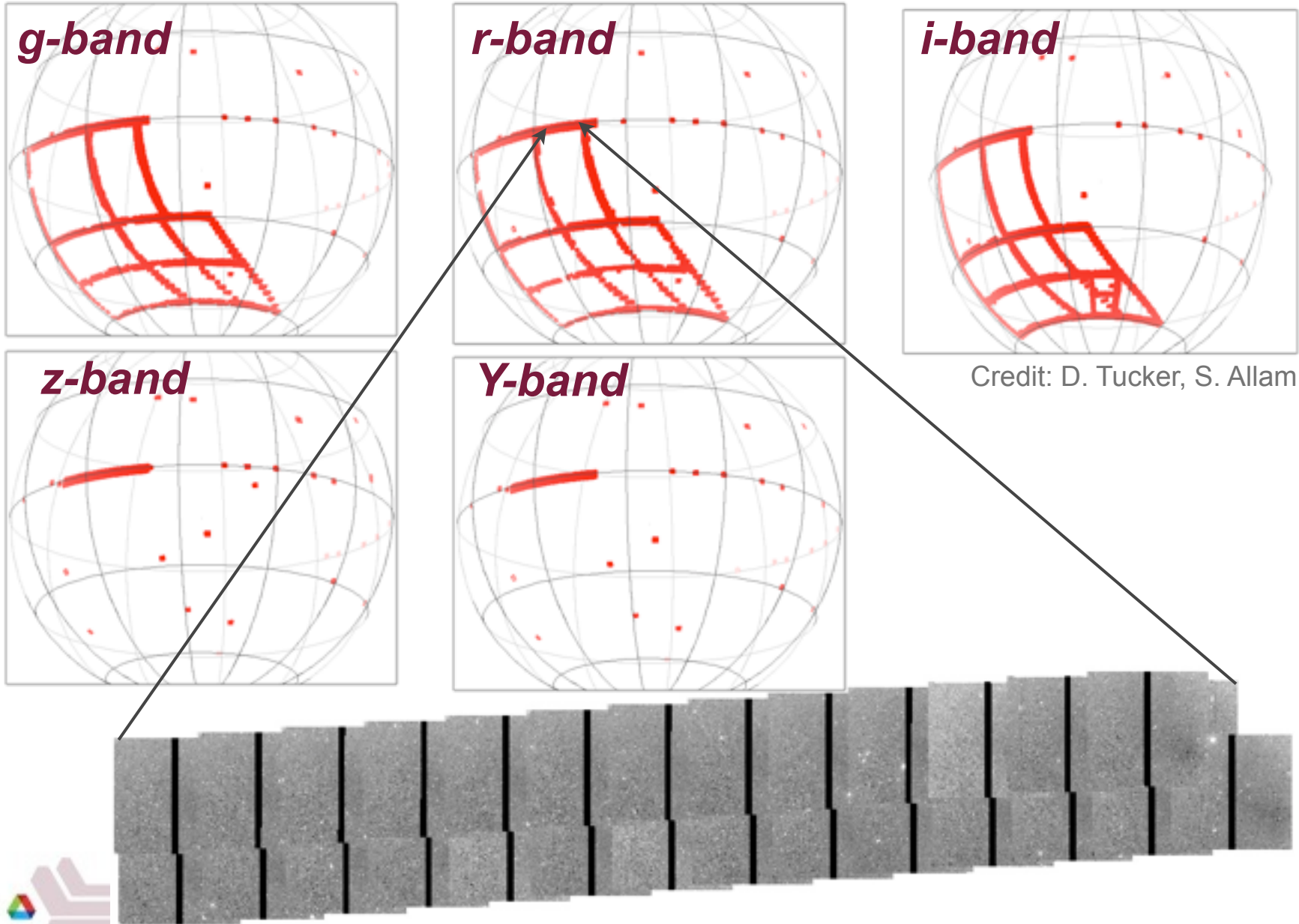
DES/PreCam Color Response



Credit: D. Tucker

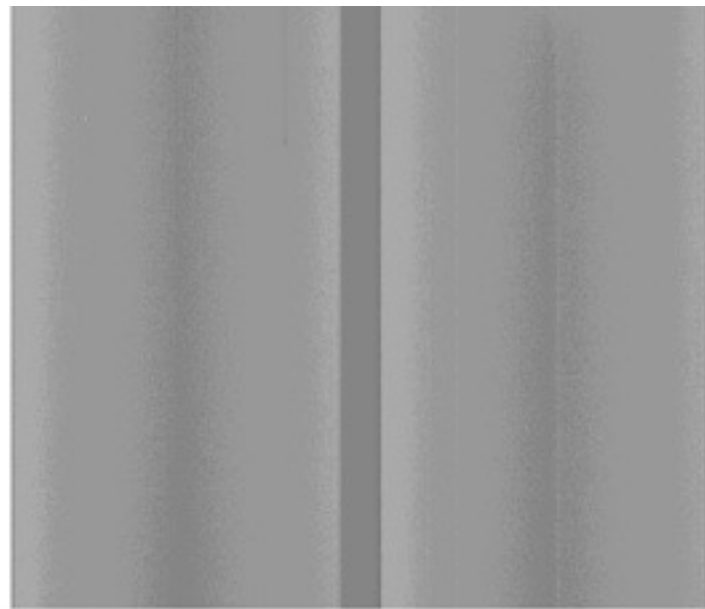
PreCam Observations by Filter

Steps to the PreCam Southern Hemisphere Standard Star Catalog



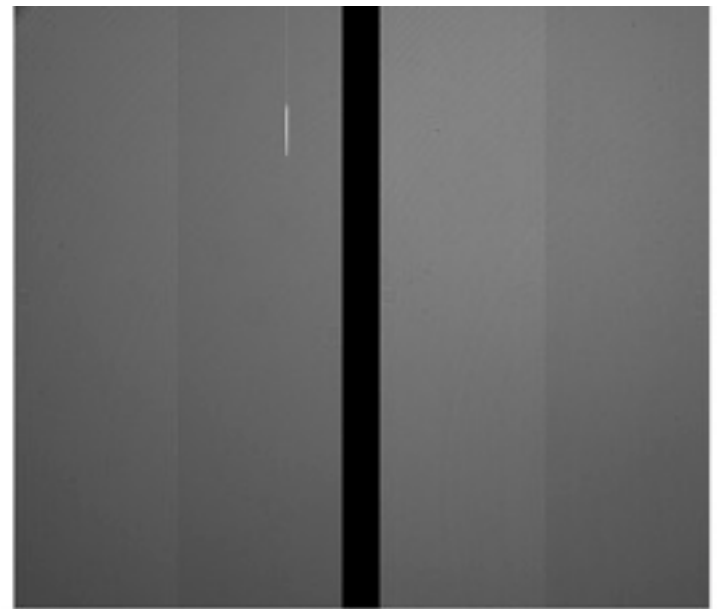
Data Processing at FNAL & ANL

- Fermilab developed processing pipeline consisting primarily of shell/py scripts for bias subtraction, flat-field corrections, etc.
- Each iteration added functionality--crucial improvements include banding/streaking removal, astrometry
- Further processing/analysis scripts developed in parallel at ANL



-4.5 -3.2 -1.9 -0.65 0.63 1.9 3.2 4.5 5.7

Bias

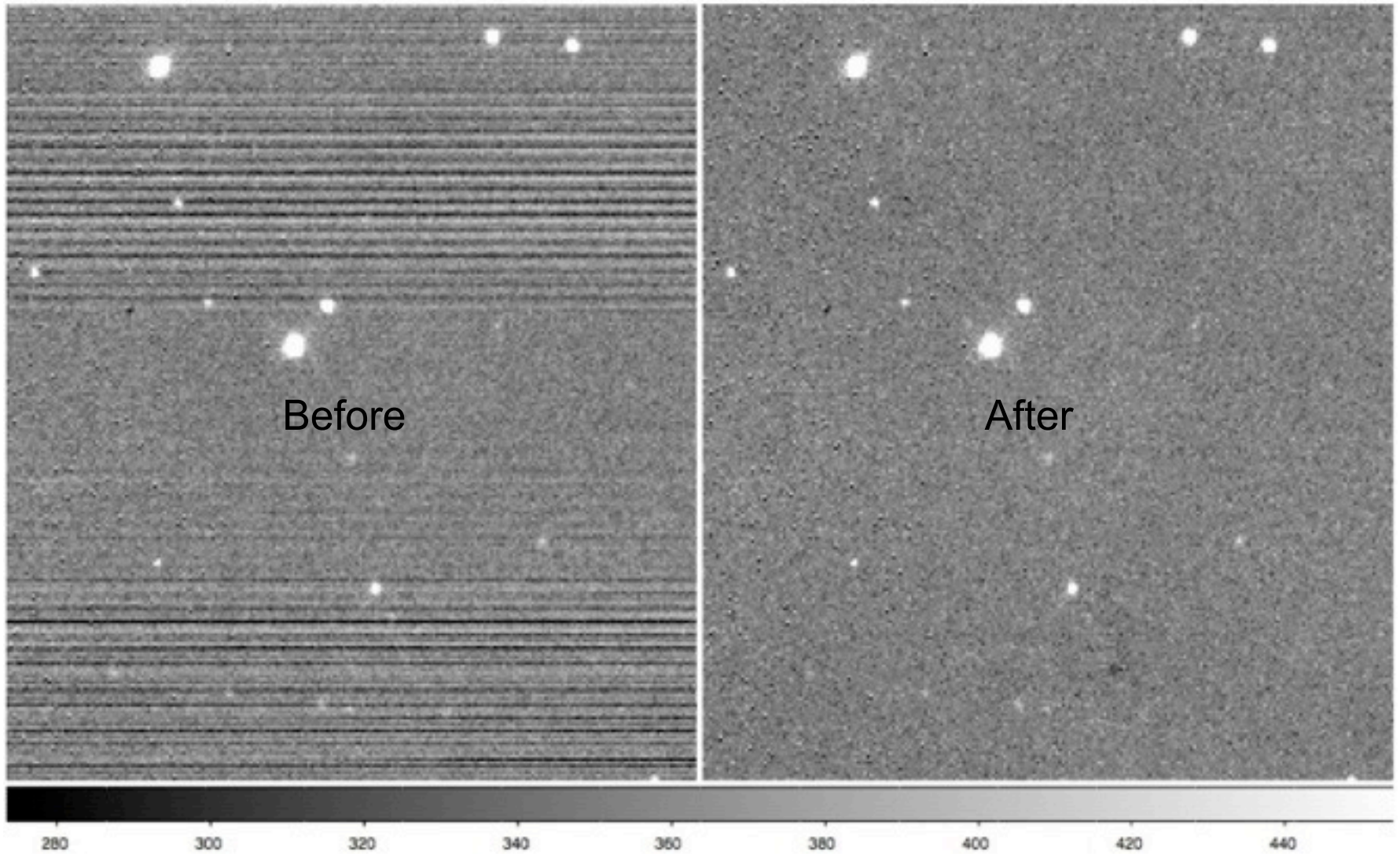


0.3 0.6 0.91 1.2 1.5 1.8 2.1 2.4 2.7

Flat

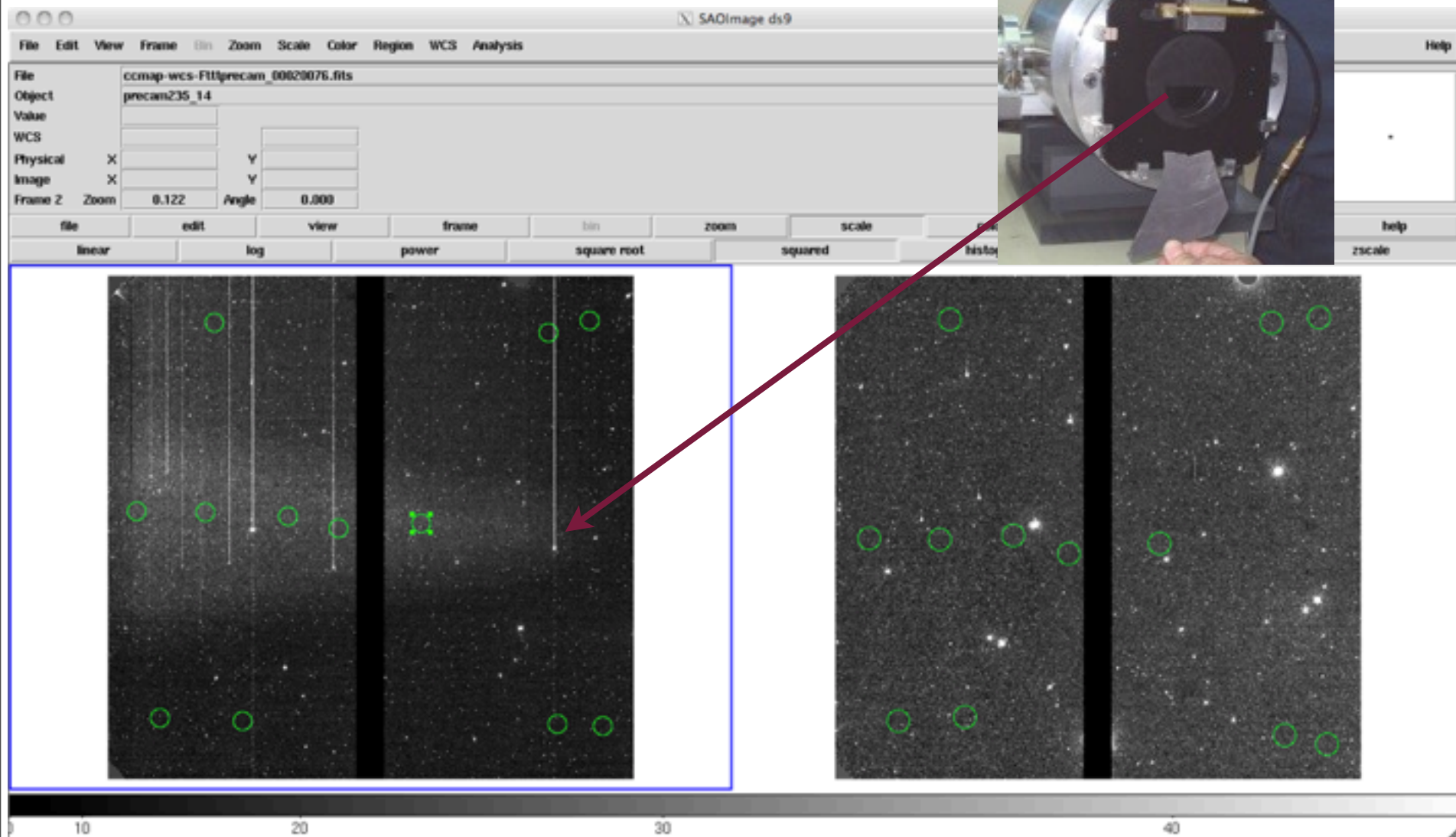


Data Processing II: Streaking/Banding & Software Corrections



Data Processing III: Identifying Problematic Shutter Images

corrected with local background subtraction

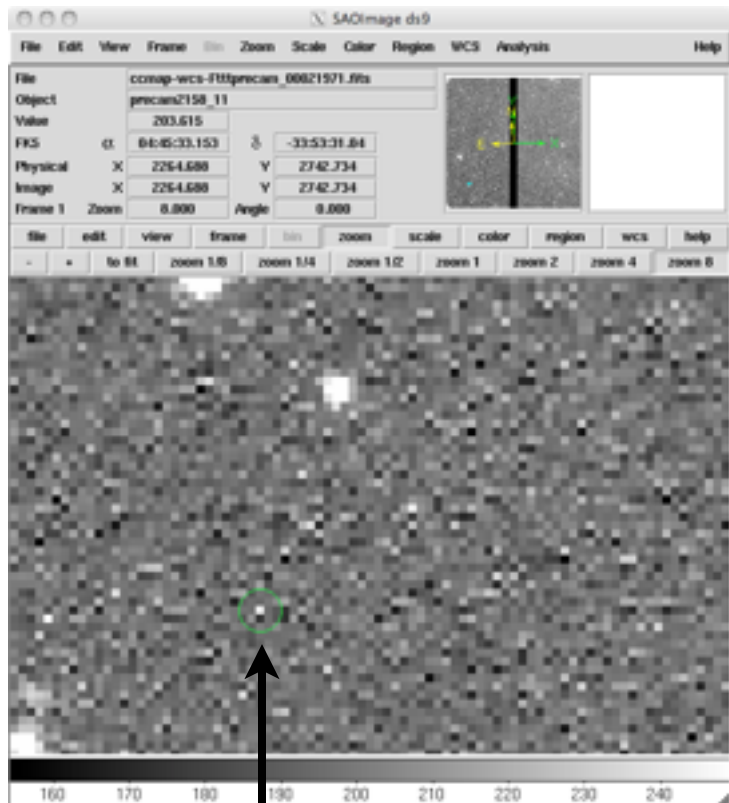


Hardware Fix: Slow-Release Valve increases shutter blade lifetime by ~3x

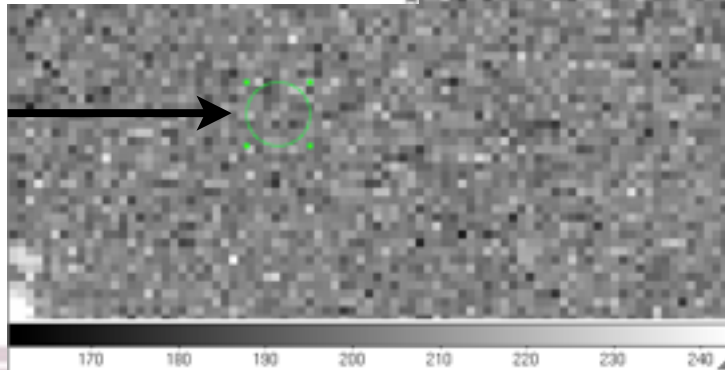


Data Processing IV: Illumination Correction

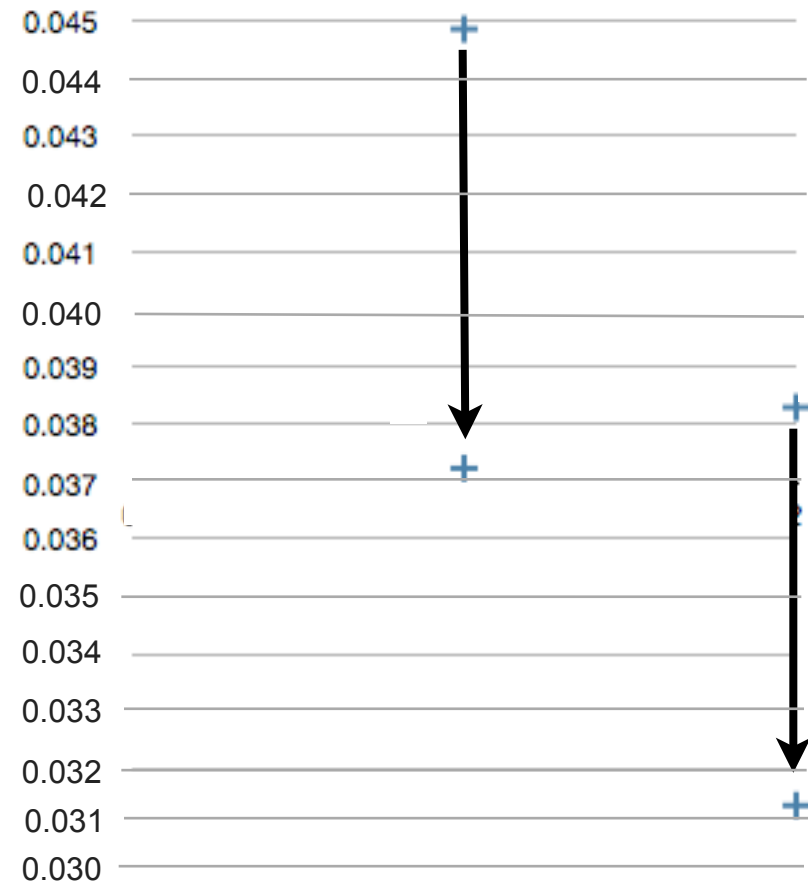
~1% improvement to i,z band photometry



Dipoles
Removed

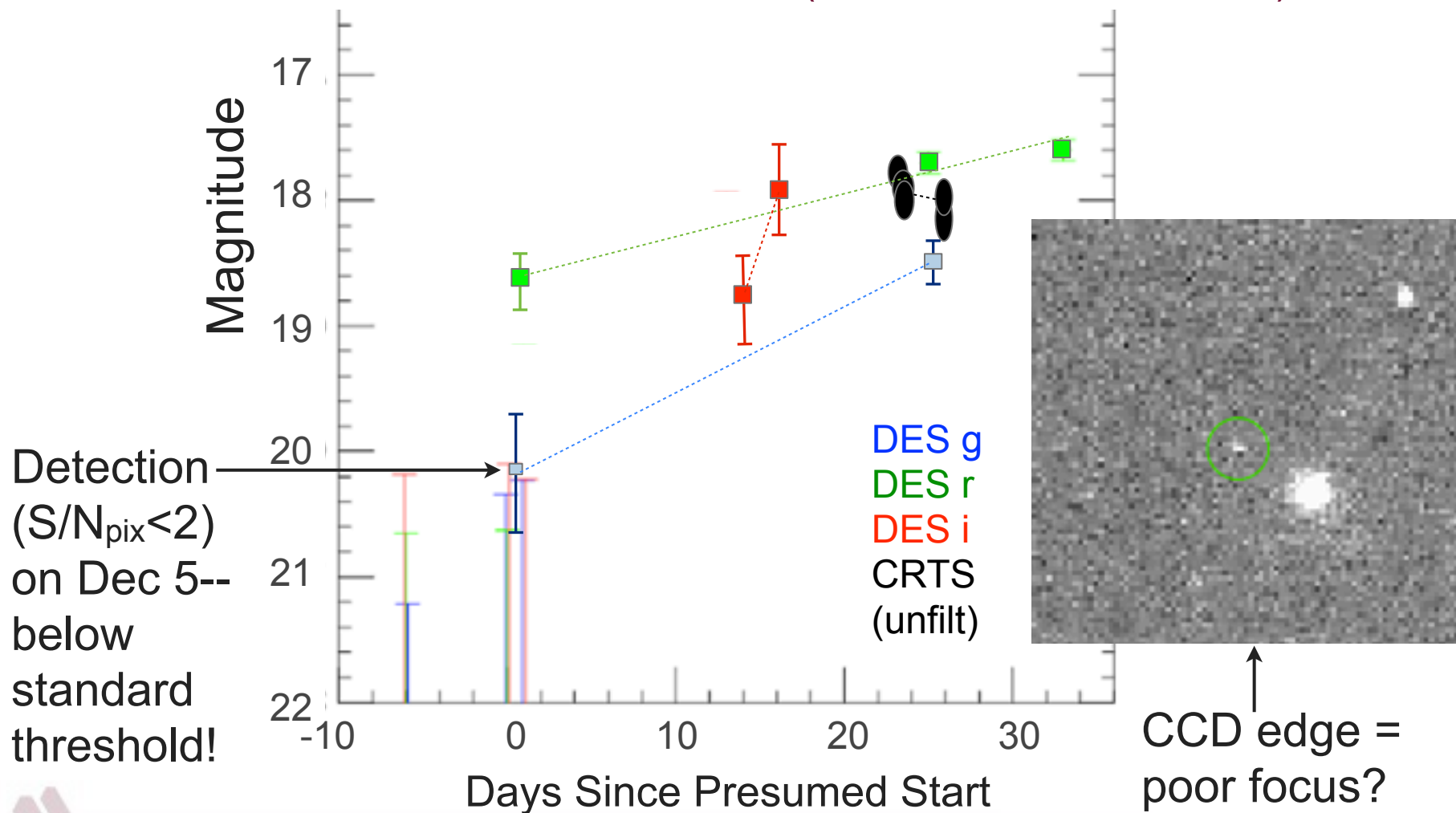


CCMAP vs. ILLUM, Z band



Data Quality Checks/DES Proof-of-Concept

PreCam gri observations from 11/29/2010 to 01/01/11 of SN2010lr, a spectroscopically confirmed SNIa associated with host galaxy 2MASX J00023401-3044061 at $z \sim 0.062$ (Drake et al., Prieto et al.)



Date	Zero-Point Offset (USNO)	Standard Deviation (USNO)	Zero-Point Offset (Southern Standards)	Standard Deviation (Southern Standards)	Zero-Point Offset (SDSS)- RA40to50	Standard Deviation (SDSS)- mag<15	Standard Deviation (SDSS)-NoMagCut
20101215			g: 2.3372 r: 2.1269 i: 2.2864 z: 2.5072	g: .05323 r: .05176 i: .05021 z: .06227	g: 2.17425 r: 1.95941 i: 2.12993 z: 2.32859	g: .05258 r: .04194 i: .0581 z: .05982	g: .08925 r: .09445 i: .1065 z: .08172
20110107	g: 2.08978 r: 1.899857 i: 2.05227 z: 2.247	g: .02374 r: .03213 i: .03222 z: .02319	g: 2.0802 r: 1.91872 i: 2.05298 z: 2.263	g: .02843 r: .04228 i: .02944 z: .04915	g: 2.0645 r: 1.9346 i: 2.07891 z: 2.2993	g: .04711 r: .04305 i: .05134 z: .05304	g: .09277 r: .09258 i: .09468 z: .08514
20110108	g: 2.1784 r: 1.98041 i: 2.1281 z: 2.3587	g: .07305 r: .06301 i: .05031 z: .05476	g: 2.12746 r: 1.93154 i: 2.24 z: 2.3044	g: .03003 r: .04221 i: .04874 z: .03008	g: 2.1617 r: 1.94502 i: 2.10669 z: 2.3456	g: .05267 r: .03744 i: .05214 z: .05843	g: .1057 r: .09614 i: .1025 z: .07865
20110112	g: 2.1035 r: 1.932 i: 2.0765 z: 2.248	g: .03165 r: .05489 i: .04316 z: .04514	g: 2.07424 r: 1.905615 i: 2.06179 z: 2.21012	g: .02947 r: .03518 i: .03624 z: .03695	g: 2.11098 r: 1.92643 i: 2.07017 z: 2.25469	g: .04387 r: .03939 i: .04554 z: .05621	g: .08868 r: .08243 i: .102 z: .08538
20110113	g: 2.08618 r: 1.90392 i: 2.05038 z: 2.21058	g: .02186 r: .02544 i: .02691 z: .02033	g: 2.07 r: 1.89748 i: 2.06527 z: 2.20684	g: .03127 r: .03662 i: .04353 z: .03638	g: 2.143606 r: 1.9298 i: z: 2.26745	g: .02575 r: .04268 i: z: .06571	g: .09088 r: .08401 i: z: .0936

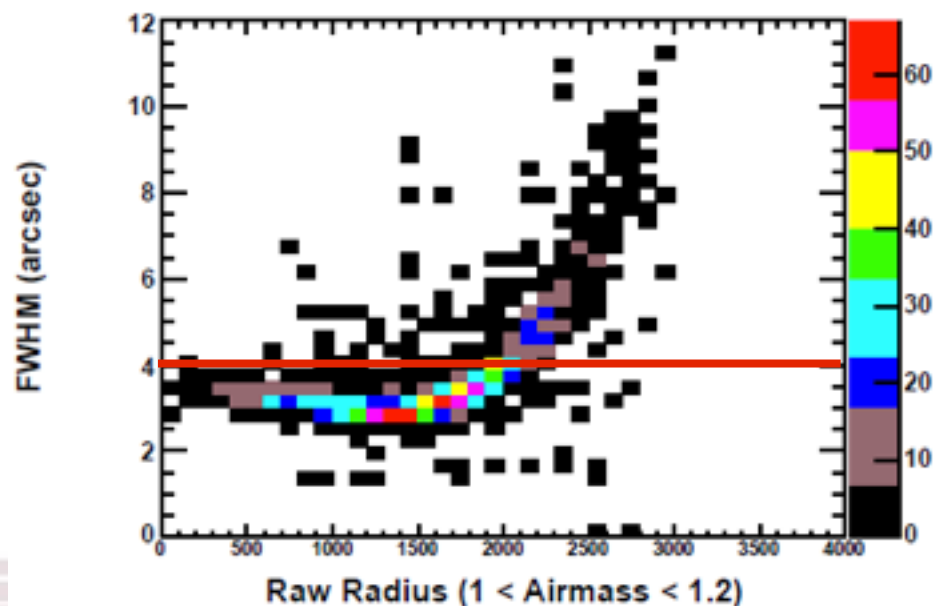
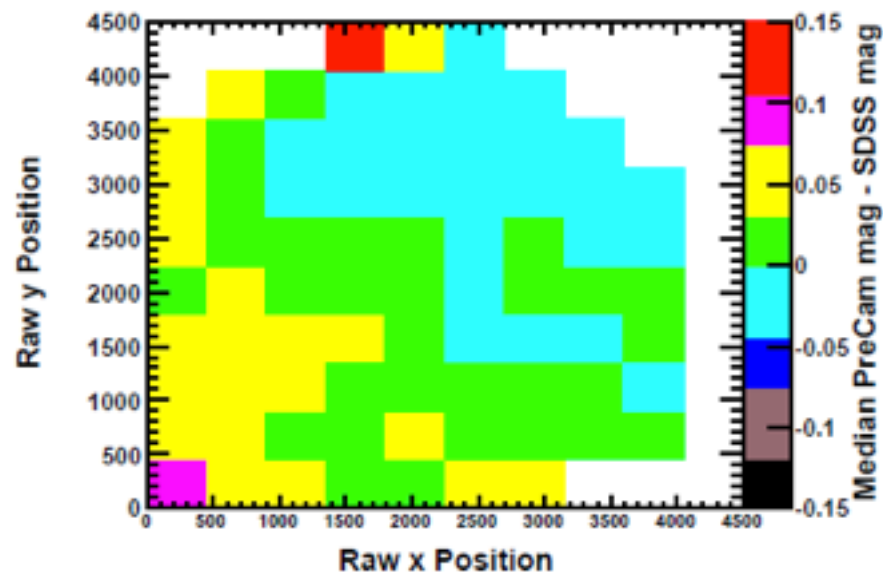
Wednesday, May 16, 2012

Final Data Analysis Steps: Star Flats + Data Quality Cuts

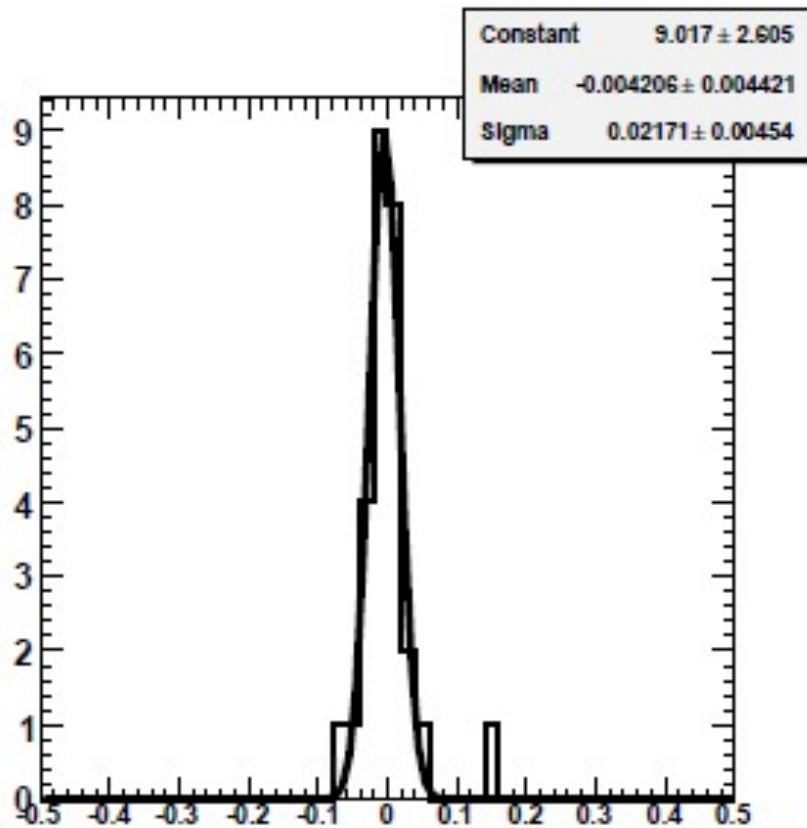
added “flat field” to remove final CCD response gradient prior to analysis

- USNO, Southern u'g'r'i'z', and SDSS standards
- SDSS airmass correction and Star Flat correction applied
- Selection Criteria:
- magerr, FWHM, Stellarity

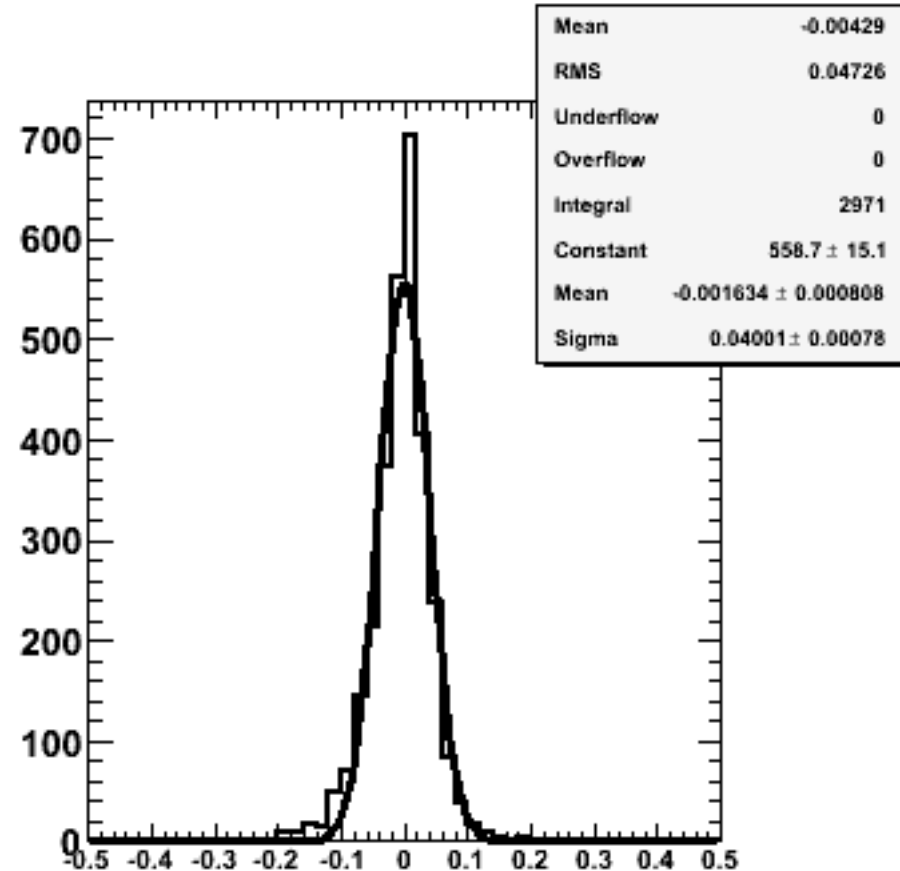
v3aper12	.06871
v3aper12, stellarity > .95	.04901
v3aper10, stellarity > .95	.048496
v3aper10, stellarity > .95, fwhm < 4.	.048434
v3aper10, stellarity > .95, fwhm < 4. , pixels cut	.048447
v3aper10, stellarity > .95, fwhm < 4. , pixels cut, starflats	.040106
v3aper10, stellarity > .95, fwhm < 4. , pixels cut, starflats, mag < 17.	.03838



Preliminary Results I: Single-Epoch Photometry



PreCam z - USNO z Bright



PreCam r - SDSS r

Preliminary Single-Image Photometric Accuracy:
4.0% (SDSS r,i); 3.2% (SDSS z); or 2.2% (USNO z, mag<14)

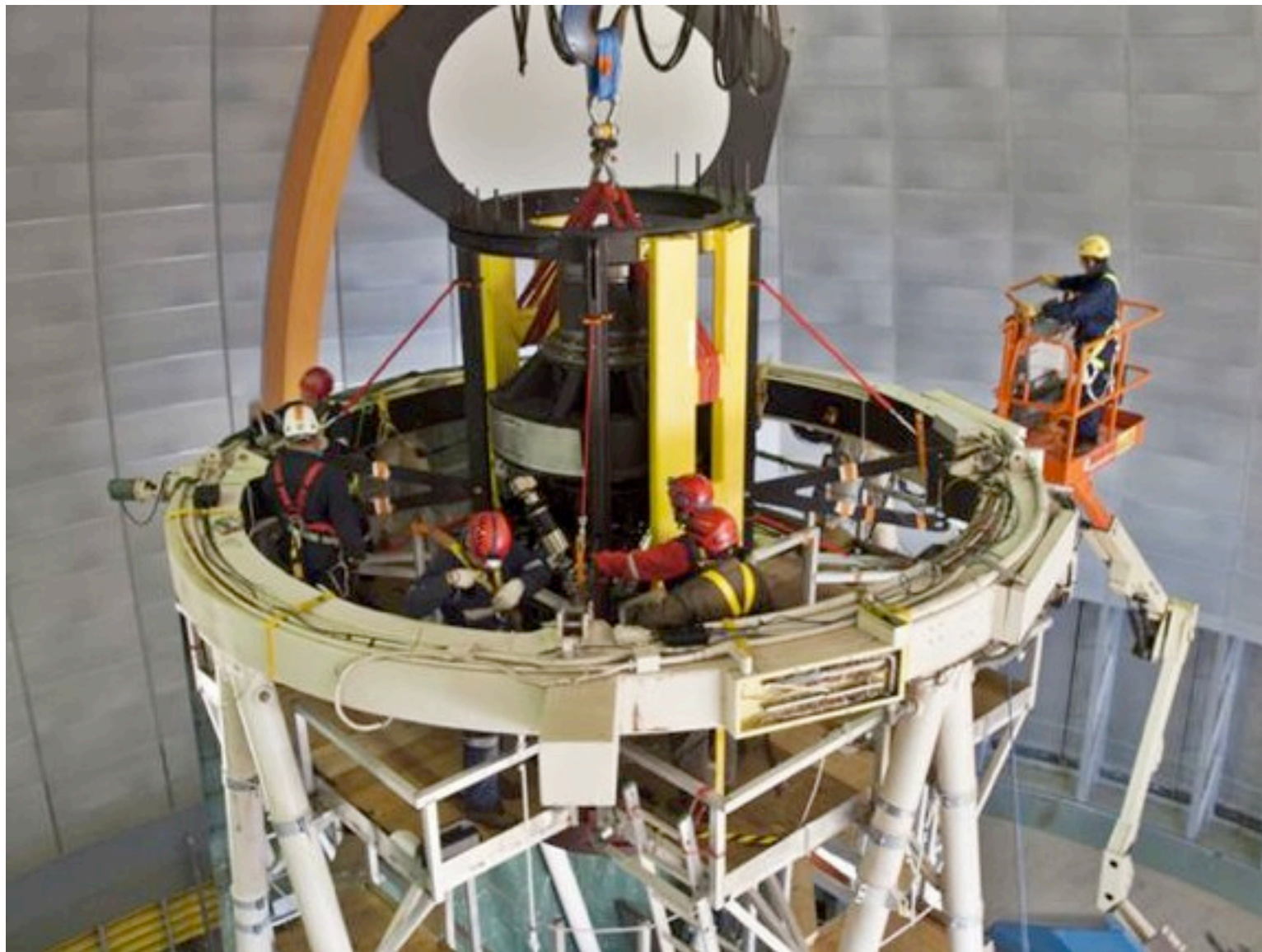


Conclusions

- Dark Energy is causing the accelerated expansion of the universe
- The Dark Energy Camera has been built to engage in the Dark Energy Survey, in order to constrain the possible source(s) of Dark Energy.
- The Precursor to the Dark Energy Camera (PreCam) has been successfully built and deployed at Cerro Tololo Interamerican Observatory
- PreCam observed a significant fraction of its total planned footprint; a second season of observations is being explored
- Preliminary results show single-epoch photometric accuracy of 3–4%, with accuracy better than 2% for brighter (<14 th mag) stars.
- The Dark Energy Survey will begin later this fall!



DECam on the Blanco Telescope!



The Dark Energy Survey Collaboration

More than 200 scientists and engineers from...

[Fermilab](#) — The Fermi National Accelerator Laboratory

[UIUC/NCSA](#) — The University of Illinois at Urbana-Champaign

[Chicago](#) — The University of Chicago

[LBNL](#) — The Lawrence Berkeley National Laboratory

[NOAO](#) — The National Optical Astronomy Observatory

United Kingdom DES Collaboration

- [UCL](#) - University College London
- [Cambridge](#) - University of Cambridge
- [Edinburgh](#) - University of Edinburgh
- [Portsmouth](#) - University of Portsmouth
- [Sussex](#) - University of Sussex
- [Nottingham](#) - University of Nottingham

Spain DES Collaboration

- [IEEC/CSIC](#) - Instituto de Ciencias del Espacio,
- [IFAE](#) - Institut de Fisica d'Altes Energies
- [CIEMAT](#) - Centro de Investigaciones Energeticas, Medioambientales y Tecnologicas

[Michigan](#) — The University of Michigan
DES-Brazil Consortium

- [ON](#) - Observatorio Nacional
- [CBPF](#) - Centro Brasileiro de Pesquisas Fisicas

[UFRGS](#) - Universidade Federal do Rio Grande do Sul

[Pennsylvania](#) — The University of Pennsylvania

[ANL](#) — Argonne National Laboratory

[OSU](#) — The Ohio State University

TAMU — Texas A&M University

Santa Cruz-SLAC-Stanford DES Consortium

- [Santa Cruz](#) - University of California Santa Cruz
- [SLAC](#) - SLAC National Accelerator Laboratory
- [Stanford](#) - Stanford University

[Munich—Universitäts-Sternwarte München](#)

- [Ludwig-Maximilians Universität](#)
- [Excellence Cluster Universe](#)